R & D Status Report No. 1
High Performance, Cost Effective Propulsion
for Advanced Navy Satellites
Report Period: March 15 - April 14, 1995

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Arlington, VA 22217-5660

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Monument, CO 80132
April 14, 1995

Project Summary

This project supports the Office of Naval Research and the Naval Research Laboratory by developing a very low mass, high thrust-to-power ion engine for improved satellite orbit altitude and inclination maneuvering capability and reduced mission cost. Proof-of-concept demonstration of a novel, low mass and volume, high performance ion engine will establish performance bounds and identify potentially life limiting engine components. The following sections describe the progress made by the Electric Propulsion Laboratory (EPL), Inc., during this reporting period towards the completion of the tasks in the Statement of Work (SOW). Attachment I to this report contains the SOW for this effort.

Task 1

Figure 1 is the preliminary EPL 7 ion engine design that will be fabricated under this contract. Novel features of the proposed design include the very low engine profile, base plate magnetic circuit with tangential propellant injection, and mass minimized grid mounting. The geometrical features introduced in the EPL 7 ion engine have the potential for providing a mass and volume minimized ion engine, in addition to a tremendous reduction in parts count, as well as improved engine thermal stability and mechanical shock resistance. Engine efficiency improvements are expected to be realized from the reduced plasma volume resulting in reduced discharge chamber wall ion recombination interactions.

The design was completed, and fabrication was initiated, on a hollow cathode and neutralizer using an EPL proprietary advanced hollow cathode electron emitter design.

The preliminary ion engine discharge chamber design is being evaluated using two types of finite element computer models, a magnetic circuit analysis and a thermal-mechanical stress analysis. The magnetic circuit analysis is performed using EMP 2.0 (from Acceleration Consultants, Inc., Albuquerque, NM) which is based on computer code developed at Los Alamos National Laboratories. The thermal-mechanical stress analysis is performed using ALGOR, Inc., software. EPL has successfully used these software design tools in many previous electric propulsion engine and component design efforts.

Magnetic circuit analysis has proven useful previously in determining the optimal position of the cathode and anode relative to the magnetic circuit; in the EPL 7 engine, this analysis will also be useful in determining the optimal position for the propellant injection. Figure 2a shows one half of a two dimensional representation of the ion engine magnetic circuit which is radially symmetric about the centerline (left hand side of the figure) with Samarium Cobalt magnetic material along the bottom of the figure (sloping line at the bottom) and two stainless

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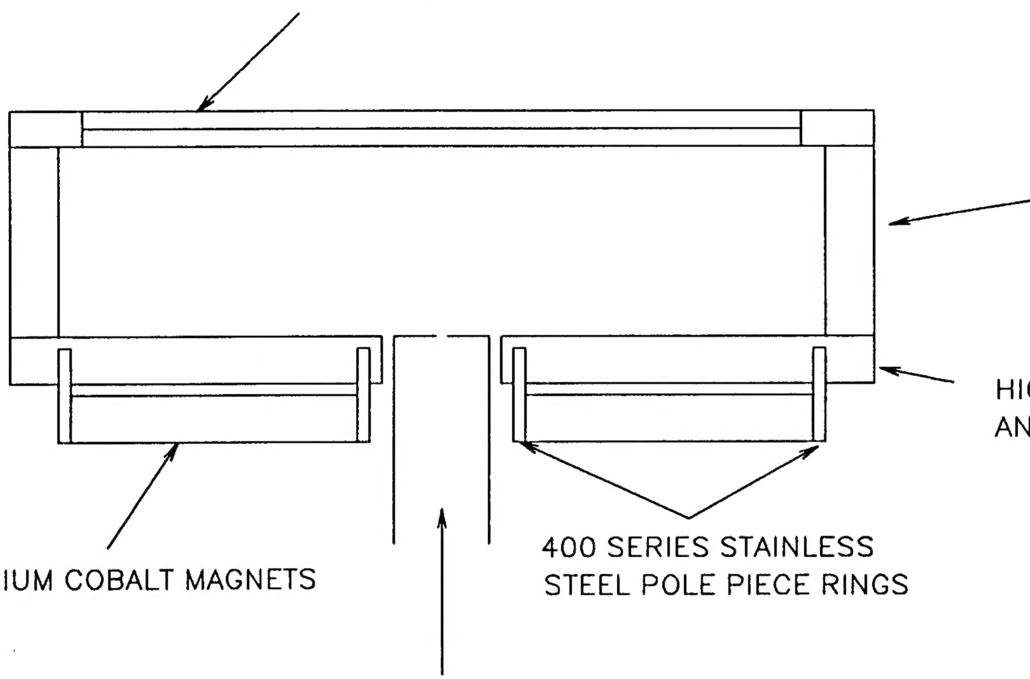
Fig. 1 Low profile concept for EPL 7 ion engine incorporates a very short discharge chamber which also serves as the insulating support structure for the ion accelerator system. The magnetic field geometry is predominately radial which minimizes the amount of high energy product magnet material, and which locates the magnets on the engine back plate where thermal loading concerns are minimized. This back plate also functions as the anode.



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TOLERANCES ARE: .XXX = +/- .001 .XX = +/- ANGLES = DEGREE +/- .5 MINUTES 64 ALL MACHINE SURFACES EXCEPT AS NOTED	TITLE / DESCRIPTION: LOW PROFILE EPL 7 ION ENGINE	
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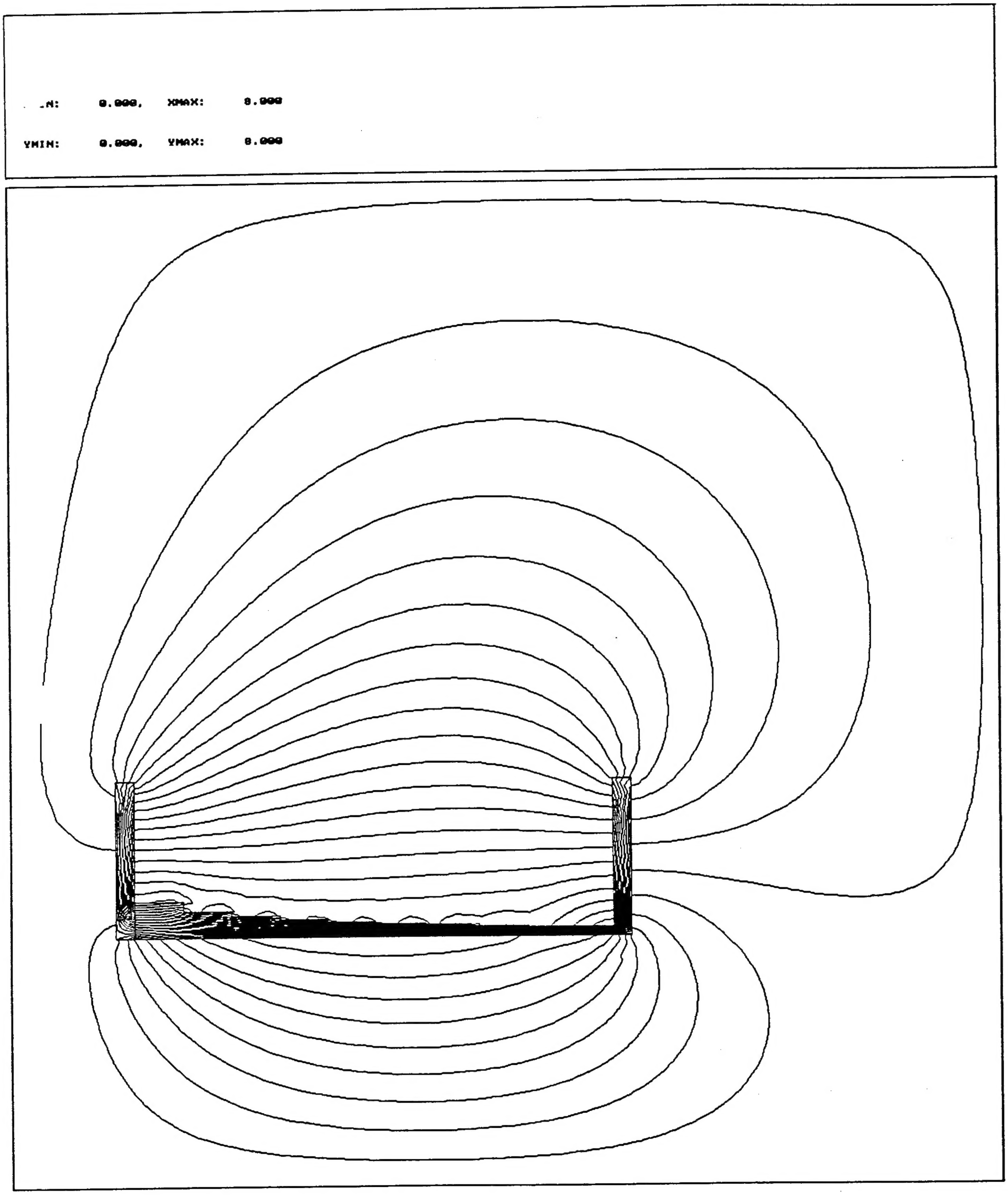

Fig. 2a Half section of predominately radial magnetic field distribution of the low profile EPL 7 ion engine concept.

steel pole pieces (upright at either end of the magnetic material). This model simulates magnets extending radially from the center of the engine to the periphery along the base of the ion engine, and the use of pole pieces to shape the magnetic field. Discharge chamber walls and grids are not included in this analysis because they are not part of the magnetic circuit. Figure 2a shows the calculated magnetic flux distribution and Fig. 2b graphs the magnetic field strength in the z direction (i.e., parallel to the pole pieces and perpendicular to the magnetic material) along the center axis of the ion engine. Further analysis will examine the effect of various changes in the magnetic circuit relative to the optimal position of the cathode and propellant injection.

Thermal-mechanical stress analysis of the ion engine will be used to project thermal expansion of the various engine components under anticipated operating conditions and thus to project the structural integrity of the engine during operation; heat loading on the magnetic circuit will also be examined. This is a sophisticated, two step analysis. The first step uses a finite element computation to estimate the steady state temperature distribution in the operating engine. Figure 3 shows typical results from the thermal analysis with temperatures in °F. In this figure, a single grid is simulated at the top and the remaining three sides simulate the discharge chamber walls, as these components represent the primary heat load components of the engine. The second step applies the steady state temperature distribution to determine the resultant mechanical stress and displacements; updated software to complete this step is on order from ALGOR.

Task 2

EPL selected Tank A at EPL to perform all ion engine tests during this program. This chamber has a diameter of 0.6 m and a length of 1.8 m, with all ion engine tests to be performed with the test engines oriented to project the ion beam down the length of the chamber. Work was started on adding the high voltage electrical and gas feed throughs into this chamber to support ion engine operation. Also, work was started on assembling a graphite target for this chamber to dump the ion beam power without incurring significant back-sputtered products into the chamber. Modification of an existing high power ion engine power system was initiated, with several laboratory power supplies replaced with smaller units better suited to the less than 1 kW input power tests that will be performed during this effort. Similarly, work was started on modifying the existing EPL electronic gas flow control system for operation at the low flow rates required to support the engine tests during this program.

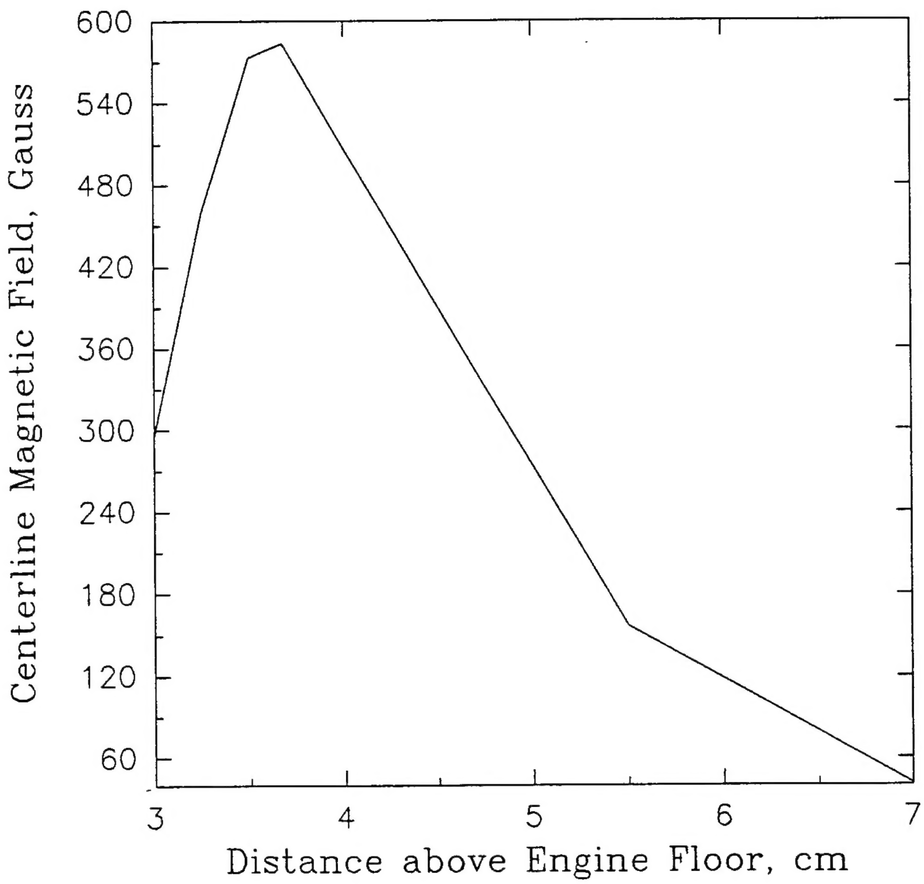

Fig. 2b Magnetic field analysis identifies location of hollow cathode orifice which should be just downstream of the peak in the centerline magnetic field intensity to avoid excessive plasma impedance coupling problems of the hollow cathode electrons to the anode.

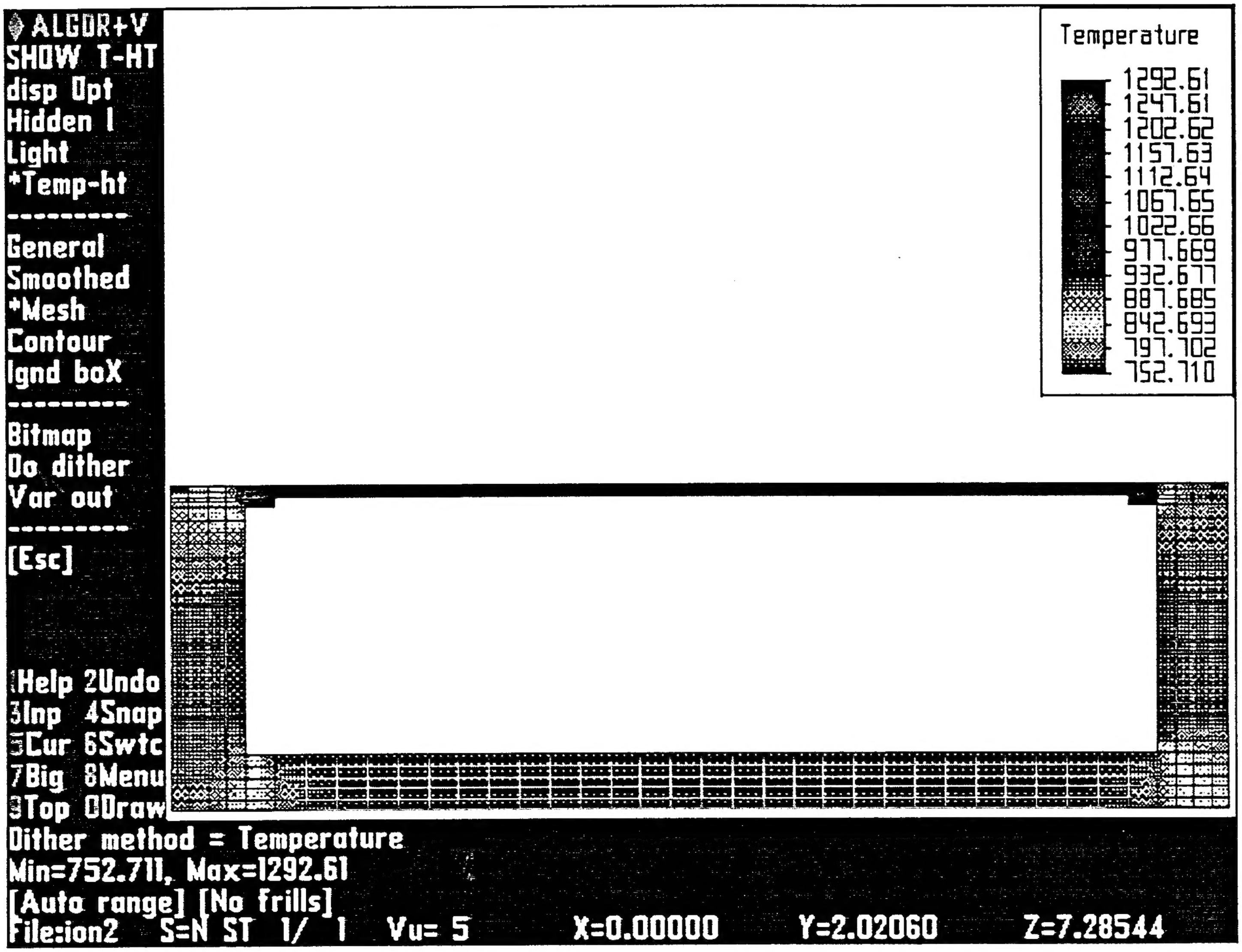

Fig. 3 EPL 7 ion engine must be dimensionally stable during operation at high input power densities and temperatures. Analysis of the mechanical stresses introduced by thermal expansion miss-matches is performed analytically to determine the level of geometrical distortion introduced into the ion engine structure; particularly the ion accelerator system.

Task 3

A vendor, Advanced Ceramics, was selected as a source of pyrolytic graphite for the EPL 7 ion engine three-grid ion accelerator system. Initial grid electrode mount designs were developed to integrate the graphite grids into a combined discharge chamber/grid mount structure as noted in Fig. 1. Work was initiated on developing a model of the three-grid ion extraction system to guide the grid electrode aperture and gap requirements, and to predict the overall performance of the ion accelerator system.

Task 4

To validate the low profile ion engine design concept introduced in Fig. 1, assembly of a test bed ion engine was initiated using existing EPL ion source hardware. This test bed ion engine is being assembled with a two-grid 10 cm beam diameter molybdenum ion accelerator system, alumina rings for the discharge chamber walls, a graphite back plate with a samarium cobalt magnetic circuit, a commercial hollow cathode, and a tungsten filament neutralizer. Fabrication of this engine is underway and initial testing is anticipated next month.

Task 5

A survey of commercial power supply manufacturers was undertaken to assess the capabilities and appropriateness of existing state-of-the-art high frequency switching power supplies to meet some of the EPL 7 power system requirements. Two vendors were selected, Kepco and ETA Electric Industries. Several power supplies were provided by these companies for evaluation at EPL. Thus far, EPL has used various combinations of the Kepco power supplies to successfully, and repeatedly, start and operate an advanced EPL hollow cathode similar to the hollow cathode and neutralizer presently being fabricated for this effort. These preliminary tests have demonstrated that existing off-the-shelf state-of-the-art high frequency switching power supplies may be a viable source for some of the power system requirements of the EPL 7 engine.

Task 6

No work was performed on this task.

Task 7

No work was performed on this task.

Current Problems

At present, no problems exist to prohibit the progress on this contract.

Attachment I

1. A proof-of-principle high thrust density plasma discharge chamber will be designed and fabricated for sustained high temperature operation. This discharge chamber will be built with a modular design to allow for modification of the magnetic filed distribution, the propellant injection location, and the hollow cathode location.

2. A test fixture will be assembled for ion beam extraction testing of the discharge chamber fabricated in Task 2. This hardware will be integrated into a large EPL diffusion pumped test facility supported by a multi-channel xenon gas flow control system and appropriate power supply and instrumentation consoles.

3. Three-grid ion accelerator systems will be designed and fabricated using pyrolytic graphite to support ion beam extraction tests up to 15 mA/cm^2 with xenon propellant. These test grid sets will be integrated to a thermally stable accelerator system mount and attached to the discharge chamber from Task 1. Assembly of these major components will constitute the prototype EPL 7 ion engine.

4. Tests will be conducted to establish the performance capability of the prototype EPL 7 ion engine concept using the hardware assembled in Task 3. Parameters measured will be the engine thrust, specific impulse, efficiency and ion beam profile characteristics as a function of parametric design changes in the discharge chamber magnetic field distribution, propellant injection location, hollow cathode position and ion accelerator system design to demonstrate the attainment of 25 mN thrust with the EPL 7 ion engine. During this test program critical engine components will be monitored to determine basic engine erosion characteristics and to identify the key parameters effecting these degradation processes.

5. Using as input the thruster power and flow requirements from Task 4, baseline designs for a functional bread board ion engine power system and flow system will be defined, with size, mass and efficiency of major components specified.

6. Based upon the results of Task 4, small flat plate carbon-carbon test sections will be machined to verify that the pyrolytic graphite accelerator system design optimized in this task can be applied to this more advanced material.

7. EPL will prepare a final report summarizing and evaluating all of the results of this Phase I investigation.